Occurrence and Distribution of Ants (Hymenoptera: Formicidae), Cockroaches (Blattodea), Centipedes (Chilopoda), and Wasps (Hymenoptera: Vespidae) of Public Health Importance on the Island of Oahu

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Abstract. The Vector Control Branch of the Hawaii Department of Health has accumulated a large volume of written inspection data on pests of public health for the island of Oahu. Ant, cockroach, centipede and wasp complaints provide the sixth, seventh, eighth and tenth greatest amounts of arthropod pest information available, following mosquito (first), other fly (second), flea (third), bee (fourth), and mite (fifth) and tick (ninth) complaints. The objectives of this study were to conduct a survey of the occurrence of ant, cockroach, centipede and wasp complaints on Oahu over a 10 year period, determine their distribution over time, graphically compare pest occurrence within and between district/areas, and correlate pest occurrence and distribution with season. Ant, cockroach, centipede and wasp data were drawn from inspection reports from 1990-1999, population information was obtained from Hawaii Census and State of Hawaii Data Books, 125 district/area geographic locations were defined, and pest occurrence and distribution were adjusted for population and mapped using ArcView GIS 3.2. Ant activity was mostly reported within the central, south and east urban districts; and the levels of ant activity were highest during the summer and fall. The primary ant species recorded were *Monomorium pharaonis* (Linnaeus), the pharaoh ant; *Camponotus variegatus* (F. Smith), the Hawaiian carpenter ant; *Ochetellus glaber* (Mayr), the glaber ant; *Paratrechina longicornis* Latreille, the crazy ant; *Solenopsis geminata* (Fabricius), the tropical fire ant; *Tapinoma melanocephalum* (Fabricius), the tiny yellow house ant; *Anoplolepis gracilipes* (F. Smith), the long-legged ant; *Pheidole megacephala* (Fabricius), the big-headed ant; and *Technomyrmex albipes* (F. Smith), the white-footed ant. Reported cockroach activity was mainly found within the central, south and east urban districts; and the levels of cockroach activity were highest during the spring and summer. The primary cockroach species recorded were *Periplaneta americana* (Linnaeus), the American cockroach; *Blattella germanica* (Linnaeus), the German cockroach; and *Diploptera punctata* (Eschscholtz), the Pacific beetle cockroach. Most centipede activity was reported within the leeward urban districts, and the levels of centipede activity were highest during the winter, summer and fall. The primary centipede species recorded was *Scolopendra subspinipes* Leach, the large centipede. Finally, wasp activity was fairly well distributed across the island, and the levels of wasp activity were highest during the fall. The primary wasp species recorded was *Polistes* sp., the paper wasp.

Key words: Ants, cockroaches, centipedes, wasps, *Monomorium pharaonis*, *Camponotus variegatus*, *Ochetellus glaber*, *Paratrechina longicornis*, *Solenopsis geminata*, *Tapinoma melanocephalum*, *Anoplolepis gracilipes*, *Pheidole megacephala*, *Technomyrmex albipes*, *Periplaneta americana*, *Blattella germanica*, *Diploptera punctata*, *Scolopendra subspinipes*, *Polistes*, public health, vector control, Oahu, GIS

Introduction

The Vector Control Branch (VCB) of the Hawaii Department of Health was created in 1970 with the merging of Rodent Control and Mosquito Control programs. The VCB is a statewide inspection, education, regulatory, prevention and control program primarily concerned with the vector-borne diseases of dengue fever, murine typhus, leptospirosis and West Nile virus. Vector Control Inspectors deal with other arthropods of public health importance in addition to insect disease vectors and vertebrate pests. As a result, the VCB has accumulated a large volume of mainly hand-written inspection data on pests of public health importance for the island of Oahu. The objectives of this study were to conduct a survey of the occurrence of public health arthropod pest problems on Oahu over a 10 year period (1990-1999), obtain a general list of arthropod related problems and determine their distribution over time, graphically compare pest occurrence within and between district/areas, correlate pest occurrence and distribution with season, and identify target areas for more efficient application of prevention, control and education programs. We report here the results obtained for ants, cockroaches, centipedes and wasps.

Ants of Hawaii. Of the 47 species of ants recorded in Hawaii (Krushelnycky et al. 2005), there are eight species that are or may be considered of public health concern on the island of Oahu (Yamada 1982, Nishida and Tenorio 1993, Tenorio and Nishida 1995). These species are *Monomorium pharaonis* (Linnaeus), the pharaoh ant; *M. floricola* (Jerdon), no common name; *Camponotus variegatus* (F. Smith), the Hawaiian carpenter ant; *Ochetellus glaber* (Mayr), the glaber ant; *Solenopsis geminata* (Fabricius), the tropical fire ant; *Pheidole megacephala* (Fabricius), the big-headed ant; *Linepithema humile* (Mayr), the Argentine ant; and *Pseudomyrmex gracilis* (Fabricius) (=*Ps. gracilis mexicanus*), the Mexican ant. These ants were first recorded in Hawaii from 1879 to 1980 (Table 1). *Camponotus variegatus, O. glaber* and *Ph. megacephala* are known to bite (Yamada 1982, Nishida and Tenorio 1993, Tenorio and Nishida 1995); and *M. pharaonis, M. floricola, S. geminata* and *Ps. gracilis* may bite and/or sting. *Linepithema humile* bites and sprays the wound with a toxic chemical (Nishida and Tenorio 1993). Other ant species encountered such as *Paratrechina longicornis* Latreille, the crazy ant; *Tapinoma melanocephalum* (Fabricius), the tiny yellow house ant; *Anoplolepis gracilipes* (F. Smith) (= *A. longipes* Jerdon), the long-legged ant; *Technomyrmex albipes* (F. Smith), the white-footed ant; *Plagiolepis alluaudi* Emery, the little yellow ant; and *M. destructor* (Jerdon), the destructive trailing ant, are considered nuisance species (Yamada 1982, Tenorio and Nishida 1995, MKHL Personal Observation). *Solenopsis geminata* and *Ps. gracilis* stings and *Li. humile* spray inflict painful burning and may cause severe allergic reactions (Nishida and Tenorio 1993, Tenorio and Nishida 1995). Some ants, especially *M. pharaonis*, are important pests in hospitals and have been shown to be potential vectors for pathogenic bacteria (Tenorio and Nishida 1995, Moreira et al. 2005).

Cockroaches of Hawaii. There are 19 species of cockroaches in Hawaii (Tenorio and Nishida 1995), with eight of these species having been found to occur in homes on Oahu (Toyama 1982, Nishida and Tenorio 1993, Tenorio and Nishida 1995). The commonly occurring cockroach species are *Blattella germanica* (Linnaeus), the German cockroach; *Periplaneta americana* (Linnaeus), the American cockroach; *Supella longipalpa* (Fabricius), the brown-banded cockroach; *Pe. australasiae* (Fabricius), the Australasian cockroach; *Neostylopyga rhombifolia* (Stoll), the harlequin cockroach; *Pycnoscelus indicus* (Linnaeus), burrowing cockroach; *Diploptera punctata* (Eschscholtz), the Pacific beetle cockroach; and *Rhyparobia (=Leucophaea) maderae* (Fabricius), the Madeira cockroach. The majority of these cockroaches were established in Hawaii by the late 1800's (Table 1). Cockroaches have been incriminated as mechanical disease vectors by the many pathogenic organisms found on their body or in their gut, feces and vomit, including those causing salmonellosis

Table 1. Year of first record for ants, cockroaches, centipedes, and wasps of public health importance on the island of Oahu.

Species	Year of first record	Original citation	Reference
Ants			
Camponotus variegatus	1879	Smith, 1879	Krushelnycky et al., 2005
Linepithema humile	1940	Zimmerman, 1941	Krushelnycky et al., 2005
Monomorium floricola	1899	Forel, 1899	Perkins and Forel, 1899
M. pharaonis	1913	Gulick, 1913	Krushelnycky et al., 2005
Ochetellus glaber (=Iridomyrmex)	1977	Beardsley, 1980	Krushelnycky et al., 2005
Pheidole megacephala	1879	Smith, 1879	Krushelnycky et al., 2005
Pseudomyrmex gracilis	1976	Beardsley, 1979	Krushelnycky et al., 2005
Solenopsis geminata	1879	Smith, 1879	Krushelnycky et al., 2005
Cockroaches			
Blattella germanica	1899	Perkins, 1899	Zimmerman, 1948
Diploptera punctata	1882	Bormans, 1882	Zimmerman, 1948
Rhyparobia mederae (=Leucophaea)	1896 or 1897	Schauinsland, 1897	Zimmerman, 1948
Neostylopyga rhombifolia	1882	Bormans, 1882	Zimmerman, 1948
Periplaneta Americana	1882	Bormans, 1882	Zimmerman, 1948
Pe. Australasiae	1899	Perkins, 1899	Zimmerman, 1948
Pycnoscelus indicus	1822	Eschscholtz, 1822	Zimmerman, 1948
Supella longipalpa	1921	Swezey, 1921	Zimmerman, 1948
Centipedes			
Scolopendra subspinipes	1847	Gervais, 1847	Shelley, 2000
Wasps			
Polistes exclamans	1951	Clagg, 1952	Clagg, 1952
Po. fuscatus aurifer	1879	Smith, 1879	Illingworth, 1923
Po. macaensis	1886	Blackburn and Cameron, 1886	Illingworth, 1923
Po. olivaceous (=macaensis)	1935	Swezey, 1936	Swezey, 1936
Sceliphron caementarium	1886	Blackburn and Cameron, 1886	Perkins and Forel, 1899
Vespula pensylvanica	1920	Williams, 1921	Williams, 1921

(*Salmonella*), dysentery (*Shigella dysenteriae* or *Entamoeba histolyica*), poliomyelitis (Poliovirus) and toxoplasmosis (*Toxoplasma*) (Ebeling 1975, Toyama 1982, Nishida and Tenorio 1993, Tenorio and Nishida 1995, Fathpour et al. 2003). *Periplaneta americana* and *Pe. australasiae* may bite humans when infestations are especially heavy, and research studies have shown that some people are allergic to *Pe. americana* and *B. germanica* (Ebeling 1975, Nishida and Tenorio 1993, Tenorio and Nishida 1995). *Pycnoscelus indicus* damages the underground parts of some plants and is known to be an intermediate host for Manson's eye worm of poultry (Nishida and Tenorio 1993, Tenorio and Nishida 1995), and *D. punctata* damages plants, particularly cypress trees, by eating the bark and girdling small branches (Toyama 1982).

Centipedes of Hawaii. Of at least 12 non-native species of centipedes present in Hawaii (Nishida and Tenorio 1993, Tenorio and Nishida 1995), only one species, *Scolopendra subspinipes* Leach, the large centipede, is of medical significance (Komatsu 1982b, Nishida and Tenorio 1993, Tenorio and Nishida 1995). *Scolopendra subspinipes*, reported to be present in Hawaii prior to 1847 and probably arriving in the islands with the Polynesians (Shelley 2000), can inflict a very painful "bite" with its enlarged first pair of legs and claws that inject venom from poison glands at the base of the legs (Komatsu 1982b, Nishida and Tenorio 1993, Tenorio and Nishida 1995). The wound can be slow to heal and may be susceptible to infection.

Wasps of Hawaii. Only seven of nearly 500 non-native wasp species were considered to be of public health importance in Hawaii (Komatsu 1982a, Nishida and Tenorio 1993, Tenorio and Nishida 1995), six of which were present on Oahu. They were *Polistes exclamans* Viereck, the common paper wasp; *Po. olivaceous* (De Geer), the red-brown paper wasp; *Po. fuscatus aurifer* Saussure, the golden paper wasp; *Po. macaensis* (Fabricius), the Macao paper wasp; *Vespula pensylvanica* (Saussure), the Western yellowjacket; and *Sceliphron caementarium* (Drury), a mud-dauber. The common yellowjacket, *V. vulgaris* (Linnaeus), was the seventh medically important wasp and is restricted to the island of Maui. These wasps were recorded in Hawaii beginning in the late 1800's (Table 1). The first year of record for *Po. olivaceous* was difficult to determine from the literature and this wasp was eventually found to be synonymous with *Po. macaensis* which was originally recorded as *Po. hebraeus* (Perkins and Forel 1899, Illingworth 1923, Harris 1979). The important wasp species range from non-aggressive, *S. caementarium*, to very aggressive, *V. pensylvanica*, but they all sting with the possibility of a severe allergic reaction or anaphylactic shock (Komatsu 1982a, Nishida and Tenorio 1993, Tenorio and Nishida 1995). *Vespula pensylvanica* is especially dangerous due to its highly aggressive nature, tendency to mass attack and the fact that a wasp's stinger is not barbed which allows it to sting repeatedly (Nishida and Tenorio 1993, Tenorio and Nishida 1995). As with bees, the severity of reactions to wasp stings varies widely among individuals from localized pain and swelling to the serious and sometimes fatal, systemic reaction (Komatsu 1982a, Nishida and Tenorio 1993, Tenorio and Nishida 1995).

This is one of a series of six related papers submitted for publication in the *Proceedings of the Hawaiian Entomological Society.*

Materials and Methods

Study Area. Oahu is the third largest and most populous of the Hawaiian Islands. It is home to ~900,000 people, has a highly urbanized southern coast, and extensive growth has recently occurred in the central and Ewa Plains areas of the island. Oahu's climate is characterized by a two-season year, mild and fairly uniform temperature conditions, striking marked geographic differences in rainfall, and a general dominance of trade-wind flow.

For a more detailed description of the area of study, see Leong and Grace (2009) or Leong (2008).

Study Methods. A comprehensive arthropod pest data set was extracted from Hawaii Department of Health Vector Control Branch inspection reports from 1990-1999. Population data were obtained from Hawaii Census 1990 and 2000 and The State of Hawaii Data Books from 1990 to 2004. The Vector Control inspection reports were reviewed and compiled into general pest categories using the reported problem on the original complaint. All together, a total of 8,936 individual pest problems were found from which 27 pest categories plus a miscellaneous category were obtained. One-hundred twenty-five district/area geographic locations with varying populations were established using community structure, geographic features and inspection report designations, and the raw pest occurrence data for each district/area were standardized by dividing by the estimated population and multiplying the decimal number generated by 10,000. District/areas with populations of less than 500 were excluded from occurrence analysis. The resulting transformed pest occurrence data were mapped on a traditional four-season basis using ArcView GIS 3.2 to create 40 maps for each of 10 major pest categories along with four additional maps each showing cumulative seasonal activity. Pest occurrence was graphically compared within and between district/areas, and pest occurrence and distribution were correlated with season. Finally, pest occurrence and distribution were evaluated using inspection data, including species identifications. See Leong and Grace (2009) or Leong (2008) for a more complete description of methods.

Results

Ant activity during the winter of 1990 was very light (1–3 complaints) and scattered across north shore, south, east and central district/areas. Complaints were mainly found along south Oahu. In winter 1991, very light ant activity was found in central, south and lower east Oahu with light peaks (4–8 complaints) occurring in Downtown on the south coast and in the east district/area of Olomana-Pohakupu. Overall ant activity was less than half as compared to the preceding fall. Ant activity in the winter of 1992 was very light in south Oahu and a light peak was present in the east in Olomana-Pohakupu. Overall activity was about a fourth that in the fall of 1991. Winter 1993 ant activity was very light and reduced to about a fifth of fall 1992 activity. Ant activity during the winter of 1994 was very light, reduced to less than half of the fall activity, and found in central, south and lower east district/areas of Oahu. The winter of 1995 saw a slight decrease in overall ant activity as compared to the previous fall with activity decreasing in south and east Oahu and increasing in central district/areas. Most of the ant activity was very light, but light peaks occurred in Iwilei and Kakaako in south Oahu and in Kahuku on the east coast. Ant activity in winter 1996 decreased by over three-fourths and occurred only as very light activity from Saint Louis Heights to Aina Haina in south Oahu. Overall ant activity in the winter of 1997 was about a fourth of fall 1996 activity. The ant activity during winter 1998 was also a fourth of the fall activity with a light peak occurring in Niu Valley in south Oahu. Ant activity decreased in the winter of 1999 as well. Overall activity was about half that in the fall with light peaks occurring in the south district/areas of Waialae Nui and Niu Valley.

Spring 1990 ant activity was found mostly along the south district/areas of Oahu, and was about two times as that in the winter. There was a cluster of ant activity on the south shore from Kaimuki-Waialae to Kalani Valley with a light peak occurring in Waialae Nui. Moderate (9–15 complaints) spikes were found in Kalani Valley and in Punaluu along east Oahu. Ant activity was noticeably reduced in the spring of 1991 at less than a third of the winter activity, and with occurrence only in central and south Oahu. In spring 1992, ant

activity increased by over two times, and light peaks were found in Iwilei and Kakaako in south Oahu and in Lanikai on the east side of the island. There was a cluster of activity from Iwilei to Makiki Heights-Tantalus. Ant activity increased slightly during the spring of 1993 from that in the winter with the activity being found on the leeward side of the island. All activity was very light. Spring 1994 ant activity increased in south Oahu with a light peak occurring in Kakaako and, as in the winter, was found in south, central and lower east district/areas. Ant activity in the spring of 1995 decreased overall. Activity peaked lightly in Kapolei in the south, and Maunawili and Kahuku in the east. Spring 1996 ant activity more than doubled from that in winter 1996. Activity peaked lightly in Waialae Iki and Portlock in south Oahu, and isolated, very light activity was reported in lower east and west district/areas. There was a slight decrease in ant activity in south Oahu during spring 1997 with the activity being very light. Ant activity in the spring of 1998 was comparable to that of the winter. Very light activity was found only in central and south Oahu. Lastly, spring 1999 showed decreased ant activity overall with isolated, very light activity occurring in north shore, central and west district/areas.

The number of district/areas reporting ant activity in summer 1990 increased from that in the spring with activity mainly occurring in south and east Oahu. Light peaks were found in Waialae Nui in the south, and Waimanalo and Yacht Club Knolls-Terrace on the east shore. Ant activity was concentrated from Kamehameha-Alewa Heights to Waialae Nui, and the peak in Waialae Nui and activity from Kaimuki-Waialae to Waialae Nui also occurred in the spring. The level of ant activity during the summer of 1991 was over five times the activity in the spring and, again, occurred mainly in south and east Oahu. There was a light peak in Heeia Kea on the east shore. Overall ant activity in the summer of 1992 was comparable to that in the spring. However, although still mainly in south Oahu, the activity was more spread out across the island. Light peaks in ant activity occurred in Kapolei in the south and Heeia Kea on the east coast. Summer 1993 ant activity increased by about three times the spring activity and nearly completely occurred in south and lower east Oahu. Light peaks were found in Iwilei and Portlock in the south, and in Maunawili and Mahinui-Kokokahi on the east shore. Ant activity during summer 1994 increased overall and remained mostly in the south and lower central district/areas. A light peak in activity occurred in Kalihi Kai on the south coast, and a small cluster was present from Aiea Heights to Foster Village. Summer 1995 ant activity showed an increase across north shore, central, south and east district/areas. Activity peaked lightly in Lanikai on the east side and moderately in Kalani Valley in south Oahu. Overall ant activity in the summer of 1996 increased by over two times from that in the spring and was mainly found on the leeward side of the island. Ant activity peaked lightly in Hahaione Valley on the south coast, and moderate spikes occurred in Mokuleia on the north shore and Kahe Point-Honokai Hale along west Oahu. Ant activity in summer 1997 was well over two times the spring activity. A light peak occurred in Maunawili in east Oahu and the remainder of the activity was found on the leeward side of the island. The ant activity during the summer of 1998 was three times that in the spring and, except for the north shore, was fairly well distributed across the island. All activity was very light. Ant activity increased in summer 1999 to over two times the spring activity. A light peak occurred in Heeia Kea in east Oahu.

In the fall of 1990, ant activity increased from that in the summer with most of the activity occurring in south Oahu. Light peaks were found in Saint Louis Heights in the south and in Mahinui-Kokokahi on the east side of the island. A moderate spike occurred in Mokuleia on the north shore. During the fall of 1991, the ant activity increased slightly overall with an increase in the number of sites with light activity. Light peaks occurred in Pupukea on the north shore, Moanalua Valley in south Oahu, Olomana-Pohakupu on the east side of the island and Maili Kai on the west coast. There was a noticeable increase in ant activity in

fall 1992 with activity about doubling in south district/areas and being concentrated from Moanalua to Kahala. A light peak occurred in Lanikai on the east coast and there was a moderate spike in activity in Kakaako along south Oahu. Fall 1993 saw a slight increase in the number of district/areas reporting ant activity. There were light peaks in Halawa Heights in central Oahu, Niu Valley on the south shore and Lanikai on the east coast. Most of the ant activity was on the leeward side of the island. There was an increase in ant activity in the fall of 1994 with most of the activity occurring from Fort Shafter to Kaimuki-Waialae in south Oahu. Light peaks in activity were found in Fort Shafter and Kakaako, and in Lanikai on the east coast. There was decreased ant activity in fall 1995, only very light activity occurred and activity was mainly in south district/areas. Fall 1996 showed an increase in overall ant activity with a decrease in peak activity from in the summer. Light peaks were found in Saint Louis Heights in south Oahu and Kaaawa on the east coast of the island. Clusters of ant activity occurred in the south from Waiau to Halawa Heights and Manoa-Woodlawn to Kahala. Ant activity during the fall of 1997 was comparable to the summer activity. Light ant activity was found in Moanalua in south Oahu and most of the activity was found on the leeward side of the island. In the fall of 1998, ant activity increased from that of in the summer and was concentrated from Ala Moana to Kahala in south Oahu. However, all activity was very light. Finally, there was an increase in ant activity during fall 1999 with, as in previous years, activity mainly occurring in leeward district/areas. A light peak in activity was found in Yacht Club Knolls-Terrace in east Oahu, and a moderate spike occurred in Kalani Valley on the south shore.

Ant activity was mostly reported within the central, south and east urban districts (Figures 1a–d). South urban districts from Kakaako to Kalani Valley along with other lower elevation areas around the perimeter of Oahu showed some of the highest numbers of complaints. The levels of ant activity were highest during the summer and fall. There were very few ant problems around the ports of entry.

The cockroach category did not contain enough data to make annual, seasonal mapping very useful. As a result, a description of annual, seasonal mapping results for cockroaches is not included. Reported cockroach activity was mostly found within the central, south and east urban districts (Figures 2a–d). The central and south urban districts of the island showed the highest number of complaints. The levels of cockroach activity were highest during the spring and summer. There were a very small number of cockroach problems around the ports of entry, only in the airport area.

The centipede category did not contain enough data to make annual, seasonal mapping useful. Most centipede activity was reported within the leeward urban districts (Figures 3a–d). South urban districts from Hawaiiloa Ridge to Kalama Valley showed the highest number of complaints, and the spring total showed a line of activity along south and central district/areas bordering undeveloped lands. The levels of centipede activity were highest during the winter, summer and fall. There were no centipede problems around the ports of entry.

The wasp category did not contain enough data to make annual, seasonal mapping useful. Wasp activity was fairly well distributed across the island (Figures 4a–d). South, east and central urban districts showed the highest number of complaints, and the levels of wasp activity were highest during the fall. There were few wasp problems around the ports of entry.

As stated above, only a small number of complaints for ant, cockroach and wasp problems around the ports of entry were reported. However, the major ports of entry, Honolulu International Airport, Sand Island and Campbell Industrial Park, could not be evaluated by adjusting for population due to their low residential population.

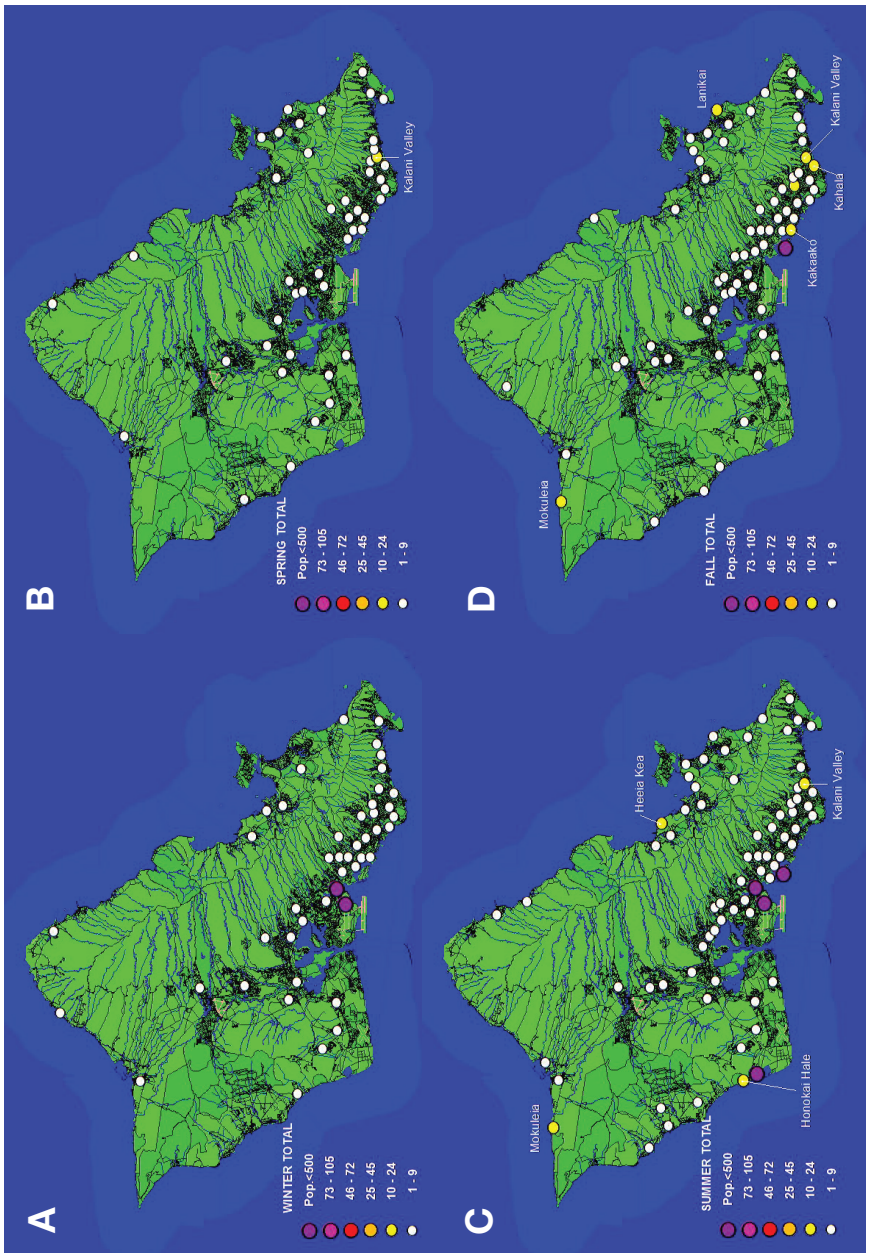

Figure 1. Ants, seasonal totals (1990–1999) for winter (a), spring (b), summer (c), and fall (d).

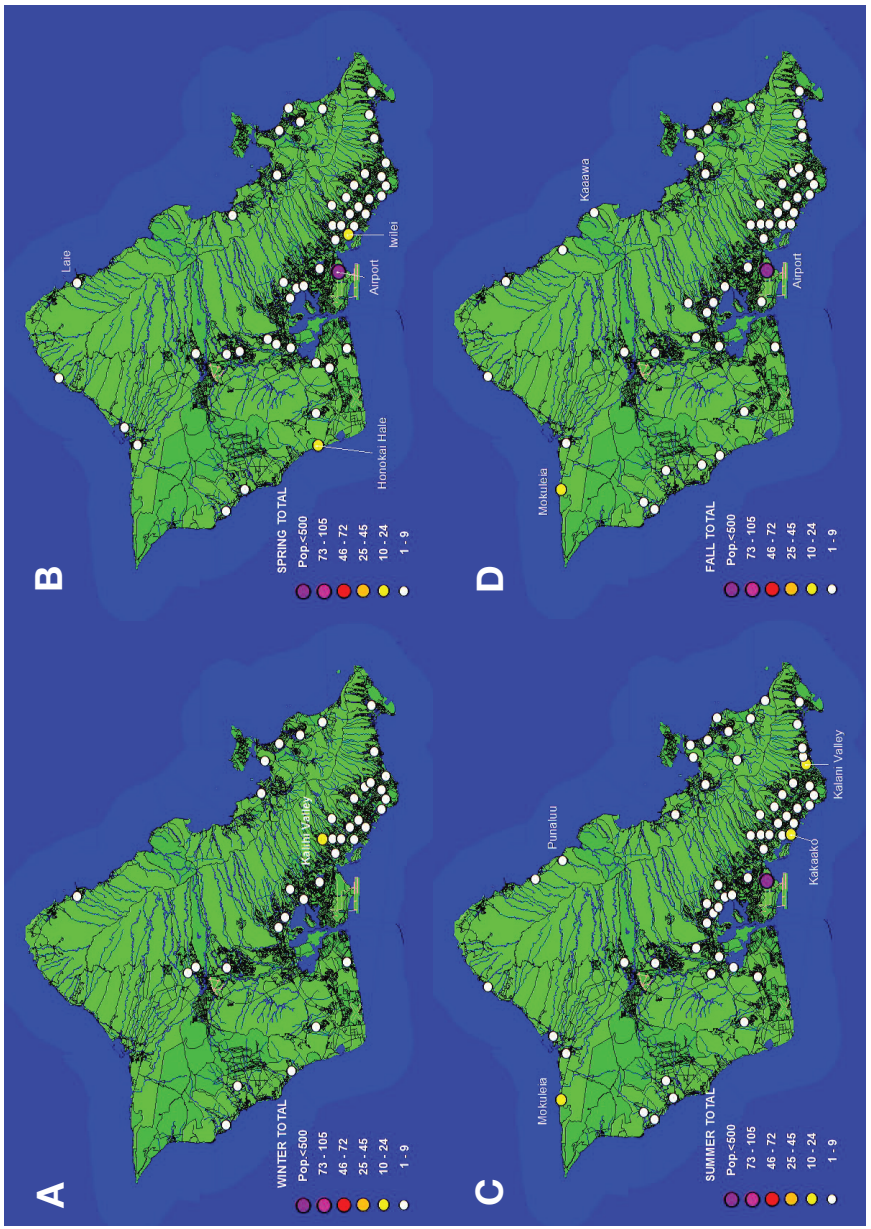

Figure 2. Cockroaches, seasonal totals (1990–1999) for winter (a), spring (b), summer (c), and fall (d).

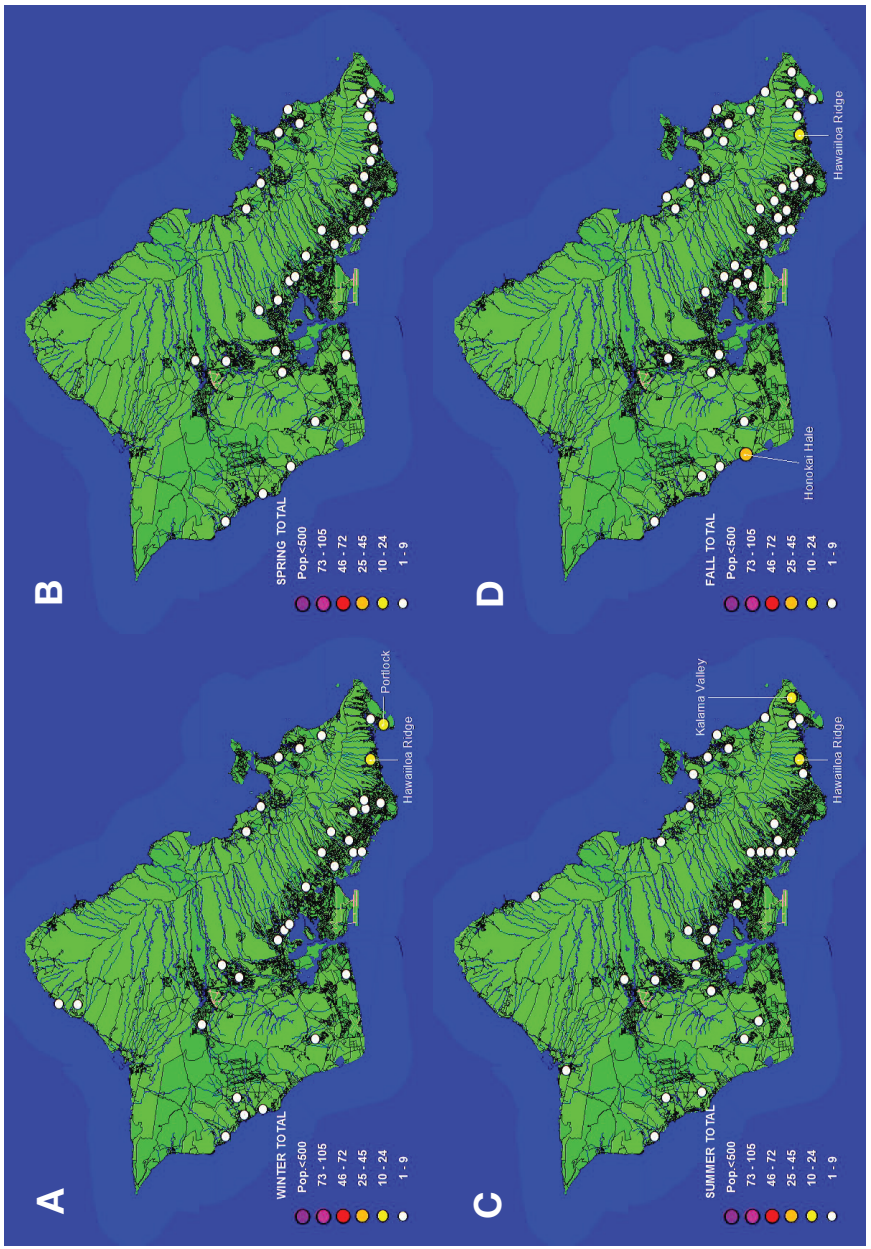

Figure 3. Centipedes, seasonal totals (1990–1999) for winter (a), spring (b), summer (c), and fall (d).

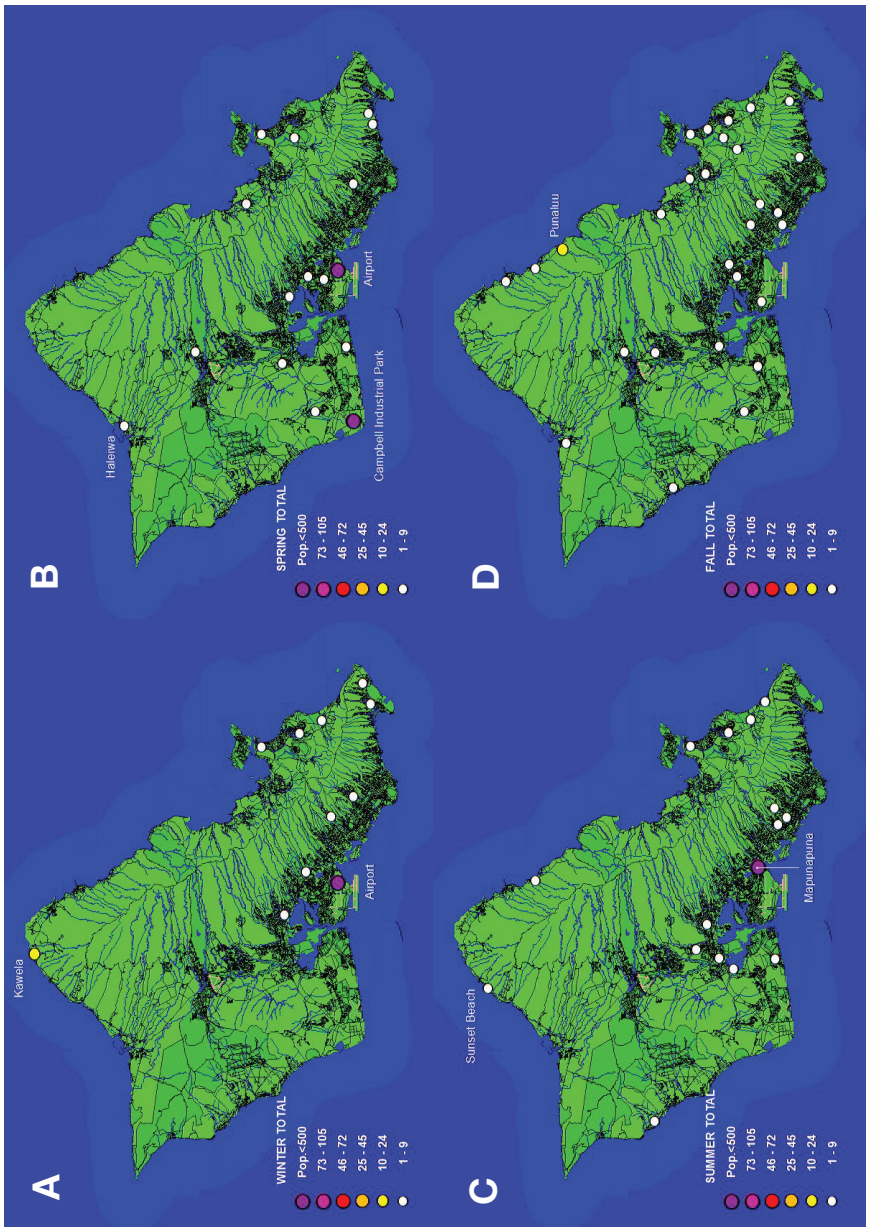

Figure 4. Wasps, seasonal totals (1990–1999) for winter (a), spring (b), summer (c), and fall (d).

Discussion

The primary ant species recorded were *Monomorium pharaonis* (~15.9%; n = 517), the pharaoh ant; *Camponotus variegatus* (~15.7%), the Hawaiian carpenter ant; *Ochetellus glaber* (~15.5%), the glaber ant; *Paratrechina longicornis* (~10.8%), the crazy ant; *Solenopsis geminata* (~9.9%), the tropical fire ant; *Tapinoma melanocephalum* (~8.7%), the tiny yellow house ant; *Anoplolepis gracilipes* (~8.3%), the long-legged ant; *Pheidole megacephala* (~5.4%), the big-headed ant; and *Technomyrmex albipes* (~4.8%), the white-footed ant (Table 2). Few *Pseudomyrmex gracilis* (~2.9%), Mexican ant; *Plagiolepis alluaudi* (~0.8%), little yellow ant; and *M. destructor* (~0.4%), destructive trailing ant, cases were recorded. The main causes of ant infestations were access to a human or natural food source, poor sanitation, openings allowing ants into a structure, and objects, plants and trees providing a bridge onto a structure. In general, ants were usually found in classrooms, kitchens and bathrooms feeding on exposed food, food crumbs and food waste, or drinking water. *Monomorium pharaonis* was often found around electrical or telephone wiring contacts; and, like *O. glaber*, *Pa. longicornis*, *Ta. melanocephalum*, *A. gracilipes* and *Te. albipes*, would invade a structure through doors, windows, wall openings and floor openings from established nests on the immediate exterior premises or on a neighboring property. *Ochetellus glaber* and *Te. albipes* were found in large numbers tending plant-sucking insects on trees and shrubs just outside or touching a building. In one case, *Te. albipes* traveled to a house along a telephone pole's vine-wrapped wires from a heavily infested, vacant property nearby. *Camponotus variegatus* was always established indoors in an isolated hollow space such as a range hood, hollow-core door or wall void, while *S. geminata* and *Ph. megacephala* were normally outdoor pests. *Solenopsis geminata* was especially a concern since it was often the species found infesting school playgrounds and public parks in addition to yards in the drier areas of the island. Ant populations are being maintained in urban areas as a result of human activities as well as naturally occurring conditions. As a result, injury from bites or stings is possible, especially in the south urban districts from Kakaako to Kalani Valley and in the drier areas of the island. The results indicate that community or island-wide educational programs should be carried out in late spring, and that residential ant surveys may be concentrated in a limited number of district/areas according to complaints received.

The primary cockroach species recorded were *Periplaneta americana* (~50.4%; n = 230), the American cockroach; *Blattella germanica* (~33.0%), the German cockroach; and *Diploptera punctata* (~10.4%), the Pacific beetle cockroach (Table 2). A small number of *Neostylopyga rhombifolia* (~2.2%), harlequin cockroach; *Supella longipalpa* (~1.3%), brown-banded cockroach; *Pycnoscelus indicus* (~0.9%), burrowing cockroach; and *Pe. australasiae* (~0.4%), Australasian cockroach, cases were recorded. The main causes of cockroach infestations were poor sanitation, garbage accumulation, access to a human or pet food source, openings allowing cockroaches into a structure, underground structures high in moisture such as the sanitary sewer and utility boxes, leaking plumbing, leaf litter accumulation, and potted plants. Poorly maintained rental apartment buildings, low-income housing and single family dwellings were found with moderate to very heavy *Pe. americana* or *B. germanica* infestations mainly in the kitchen and bathrooms as well as in garbage container or dumpster enclosures. Garbage accumulation and exposed human or pet food were often present inside and outside of the buildings in these situations. Openings beneath doors, window screens in disrepair, and holes in indoor and exterior walls and flooring allowed the cockroaches into the structures and to infest multiple units in a building via wall voids and attic spaces. *Periplaneta americana* preferred the high moisture conditions found in sanitary sewers, utility boxes, and kitchens and bathrooms with leaking plumbing. *Diploptera punctata* was generally an outdoor pest found beneath leaf litter accumulation

and around the base of plants, but they would enter homes both in potted plants and through openings beneath doors. Cockroach populations are being maintained in urban districts by human activities. As a result, disease transmission is possible, especially in the central and south urban districts of Oahu. The results indicate that community or island-wide educational programs should be carried out in late winter, and that residential cockroach surveys may be concentrated in a limited number of district/areas according to complaints received.

The primary centipede species recorded was *Scolopendra subspinipes* (~100.0%; n = 71), the large centipede (Table 2). No other centipede species were found to be a public health concern. The main sources of centipede infestations were various ground covers such as wedelia (*Wedelia trilobata*), leaf litter accumulation, red wood chips, gravel, rock piles and wood piles. Undeveloped neighboring properties were also a source of centipede activity. These sites provided habitats for various insects, worms and slugs on which centipedes feed (Komatsu 1982b, Nishida and Tenorio 1993, Tenorio and Nishida 1995, Shelley 2000) in addition to protective cover. Heavy rains have been known to flood the centipedes out of their low-lying homes and up into nearby human dwellings. Centipede activity is being maintained in urban areas by human activities as well as naturally occurring conditions. As a result, injury from centipede "bites" is possible, especially from Hawaiiloa Ridge to Kalama Valley. The results indicate that community or island-wide educational programs should be carried out in late spring, and that residential centipede surveys may be concentrated in a limited number of district/ areas according to complaints received.

The primary wasp species recorded was *Polistes* sp. (~93.2%; n = 59), the paper wasp (Table 2). A few cases involving *Po. macaensis* (=*Po. olivaceous*) (~3.4%), the Macao paper wasp; *Sceliphron caementarium* (1.7%), a mud-dauber; and *Liris aurulentus* (=*opulenta*) (~1.7%), a sphecid wasp, were recorded. Specific species identification of paper wasps was not often done since, in addition to the potential for Inspectors to be stung during specimen collecting, the abatement recommendations for treatment and removal of the wasps and nests were the same for all of the species. Paper wasp infestations usually involved several to a dozen or more small to moderate size nests hanging beneath eaves and on walls, and problem sites bordered undeveloped lands or overgrown residential premises on which adult wasps may forage for caterpillars, other insects, honeydew and juices of fruits (Komatsu 1982a, Tenorio and Nishida 1995). Infestations involving a large number of nests normally occurred on single structures that were not being properly maintained. Wasp activity regularly occurs in urban areas as a result of human activities. As a result, injury from wasp stings is possible, especially along south, east and central Oahu. The results indicate that community or island-wide educational programs should be carried out in late summer, and that residential wasp surveys may be concentrated in a limited number of district/areas according to complaints received.

Educational activities for ant, cockroach, centipede and wasp complaints are currently conducted only on a limited basis during inspections. A more comprehensive educational program would better inform the public and help to reduce the potential for pest related illness and injury. Inspections conducted in response to complaints have confirmed the practicality of using small-target area surveys to reach the people who most need the information since ant, cockroach, centipede and wasp infestations were usually restricted to the problem site reported or occurred within one or two premises of the source. Moreover, conducting presentations on these pests as well as other pests of public health importance in public schools and recreation centers would not only benefit the schools and parks affected, but also provide avenues to disseminate pest prevention and control information to the community.

Geographic analysis will help to target areas and times of the year for more efficient ap-

Table 2. Species occurrence as determined by Vector Control inspection reports.

Species	%	Mean	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Total
Ants[1]													
Anoplolepis gracilipes (=longipes)	8.3	4.3	2	3	3	3	5	13	6	4	1	3	**43**
Camponotus variegatus	15.7	8.1	23	16	9	5	11	8	4	2	2	1	**81**
Hypoponera punctatissima	0.2	0.1	0	0	0	0	1	0	0	0	0	0	**1**
Leptogenys falcigera	0.2	0.1	0	0	1	0	0	0	0	0	0	0	**1**
Monomorium sp.	0.4	0.2	0	0	1	0	0	0	0	0	0	1	**2**
M. destructor	0.4	0.2	0	0	0	0	0	0	0	0	2	0	**2**
M. pharaonis	15.9	8.2	22	14	7	7	5	11	6	5	4	1	**82**
Ochetellus glaber (=Iridomyrmex)	15.5	8.0	15	11	9	5	6	11	11	4	3	5	**80**
Paratrechina bourbonica	0.2	0.1	0	0	0	0	0	0	0	0	1	0	**1**
Pa. longicornis	10.8	5.6	5	4	11	5	4	11	9	3	3	1	**56**
Pheidole megacephala	5.4	2.8	6	4	4	2	2	4	1	2	2	1	**28**
Plagiolepis alluaudi	0.8	0.4	0	1	1	0	0	0	1	0	0	1	**4**
Pseudomyrmex gracilis	2.9	1.5	2	1	2	1	1	0	4	1	1	2	**15**
Solenopsis geminata	9.9	5.1	3	6	5	5	3	8	7	4	4	6	**51**
Tapinoma melanocephalum	8.7	4.5	12	5	8	4	4	5	2	2	1	2	**45**
Technomyrmex albipes	4.8	2.5	0	0	0	0	1	1	2	3	9	9	**25**
Total	**100.0**	**51.7**	**90**	**65**	**61**	**37**	**43**	**72**	**53**	**30**	**33**	**33**	**517**

Table 2. (contin;ued)

Species	%	Mean	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Total
Cockroaches[1]													
Balta sp.	0.4	0.1	0	0	0	1	0	0	0	0	0	0	**1**
Blattella germanica	33.0	7.6	1	15	12	3	5	5	13	5	3	14	**76**
Diploptera punctata	10.4	2.4	7	3	0	2	2	2	3	0	1	4	**24**
Euthyrrhapha pacifica	0.4	0.1	0	0	0	0	0	0	0	0	0	1	**1**
Neostylopyga rhombifolia	2.2	0.5	1	1	0	0	1	1	0	0	1	0	**5**
Periplaneta sp.	0.4	0.1	1	0	0	0	0	0	0	0	0	0	**1**
Pe. Americana	50.4	11.6	18	10	6	6	6	11	24	15	10	10	**116**
Pe. Australasiae	0.4	0.1	0	0	1	0	0	0	0	0	0	0	**1**
Pycnoscelus indicus	0.9	0.2	1	0	0	0	0	0	1	0	0	0	**2**
Supella longipalpa	1.3	0.3	0	0	0	0	0	0	1	1	0	1	**3**
Total	**100.0**	**23.0**	**29**	**29**	**19**	**12**	**14**	**19**	**42**	**21**	**15**	**30**	**230**
Centipedes[1]													
Scolopendra subspinipes	100.0	7.1	5	17	11	7	5	11	5	3	2	5	**71**
Total	**100.0**	**7.1**	**5**	**17**	**11**	**7**	**5**	**11**	**5**	**3**	**2**	**5**	**71**
Wasps[1]													
Liris aurulentus (=opulenta)	1.7	0.1	0	0	0	0	0	0	0	0	1	0	**1**
Polistes sp.	93.2	5.5	9	8	7	5	5	4	7	6	3	1	**55**
P. macaensis (=olivaceous)	3.4	0.2	0	1	0	0	0	1	0	0	0	0	**2**
Sceliphron caementarium	1.7	0.1	1	0	0	0	0	0	0	0	0	0	**1**
Total	**100.0**	**5.9**	**10**	**9**	**7**	**5**	**5**	**5**	**7**	**6**	**4**	**1**	**59**

[1]Ants = 495 reports, cockroaches = 445 reports, centipedes = 221 reports, wasps = 75 reports.

plication of ant, cockroach, centipede and wasp prevention, control and education programs by continuously tracking pest activity using Vector Control inspection reports. Improvements in methodology include using the actual number of complaints within a district/area and the severity of the pest infestation found together with data adjusted for population to more accurately determine the need for targeted survey, abatement and education efforts. For example, geographic analysis of transformed ant, cockroach, centipede or wasp occurrence may flag a potential problem district/area for increased scrutiny, but additional action would be taken only if at least three complaints were received, the level of infestation was heavy and/or the pest problem was found to occur over an extensive area. The same deciding factors may be applied directly for the excluded district/areas with resident populations of less than 500.

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